MIT International Center for Air Transportation

Quantifying Noise from Advanced Operational Approach Procedures of Current and Future Aircraft

Jacqueline Thomas
thomasj1@mit.edu
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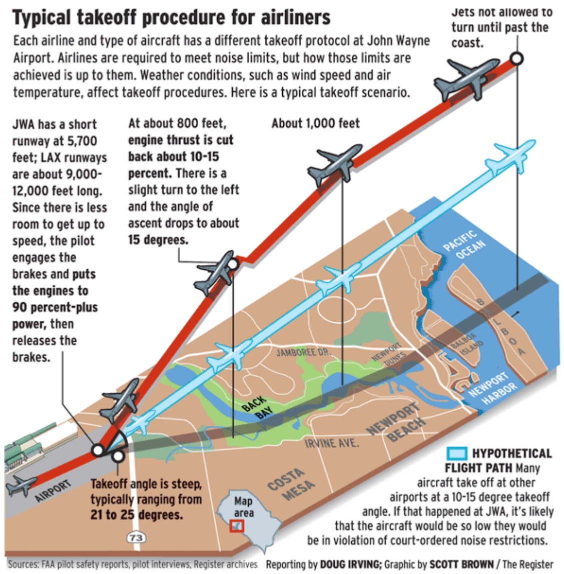
Two Approaches for Reducing Aircraft Noise

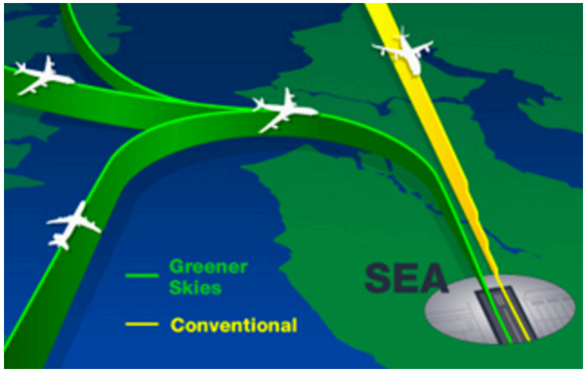
Advanced Operational Procedures

- Flight trajectory adjustments
- Scheduling trust cutbacks

- Continuous descent approaches
- Delayed deceleration approaches
- RNAV (GPS guided) approaches



Thrust Cutback on Takeoff at SNA[1]



RNAV Approaches at SEA[2]

New Configurations

- Cleaner Airframes
- Engine Noise Shielding

D-8 Aircraft Concept[3]

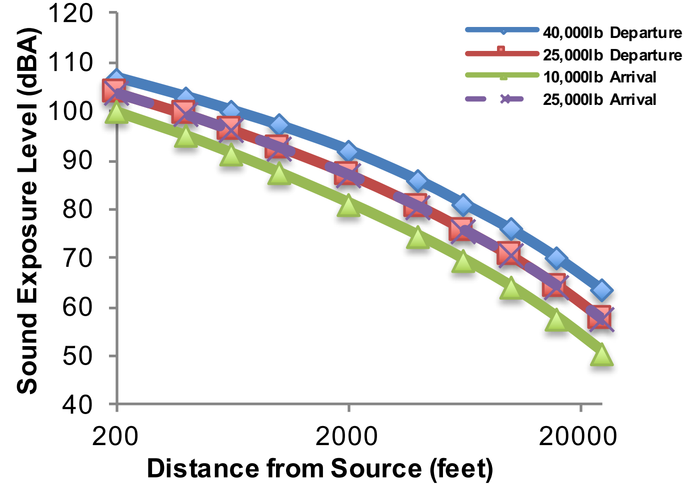
- Project Goal: to expand analysis capabilities to enable the modeling the noise impacts of advanced operational procedures for <u>current</u> and <u>future</u> aircraft designs

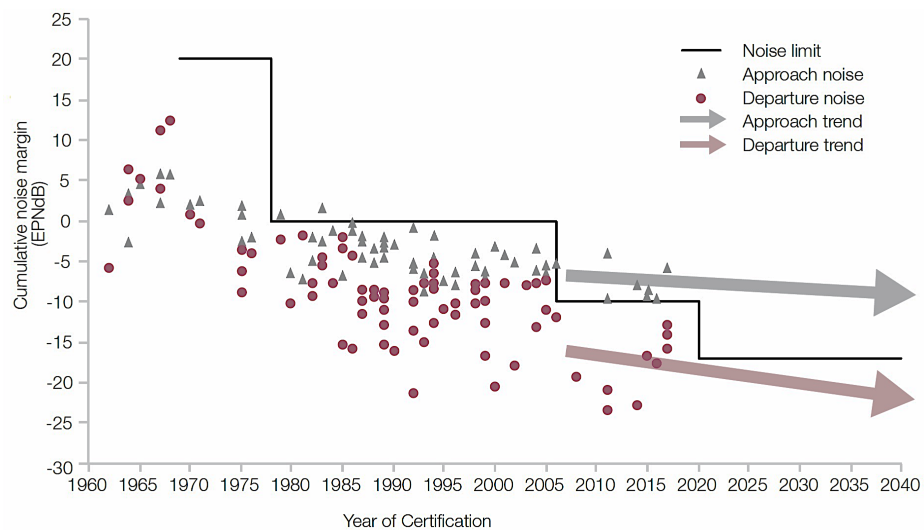
[1] Irvine, Doug (2012)
[2] FAA (2012)
[3] NASA (2015)

Limitations of Current Standard Noise Analysis Method: Aircraft Environmental Design Tool (AEDT)

- AEDT the current industry standard model to evaluate aircraft noise impacts[4]
- Noise-Power-Distance (NPD) based computations
- AEDT/INM analysis assumes engine noise dominates aerodynamic noise
  - Assumption may have been valid only for earlier generation jet engines

Noise Power Distance (NPD) Curves
GE CF6-50 (Airbus A300)





Historic and Predicted Aircraft Noise Trends by Year Show Less Decrease in Approach Noise Compared to Departure Noise[5]

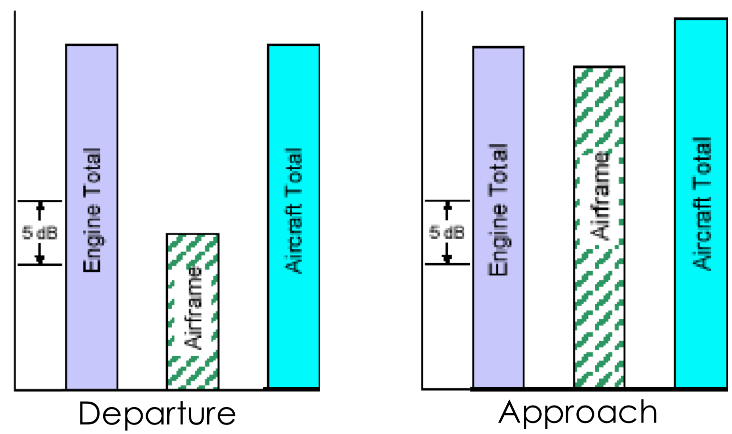
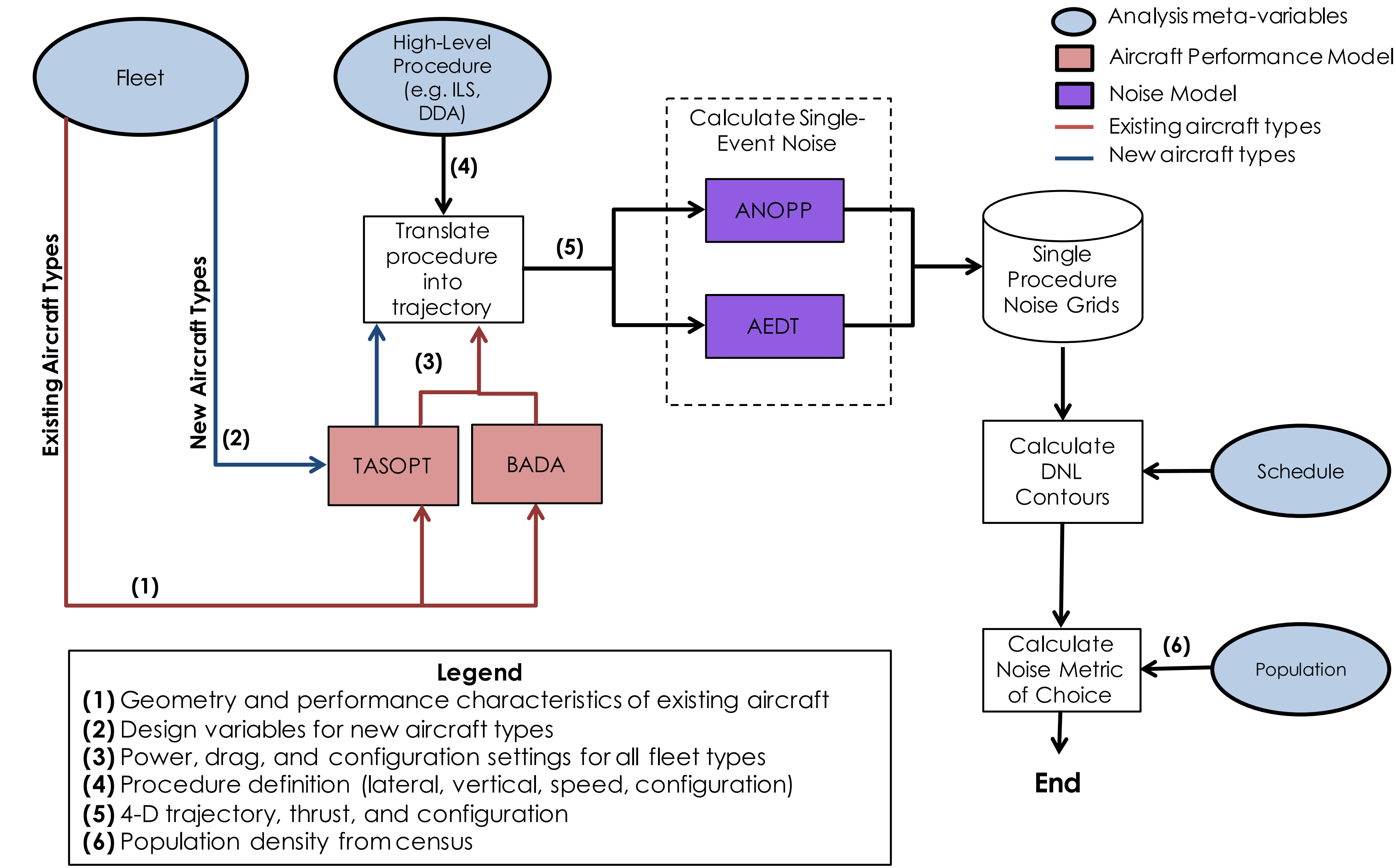


Illustration of Component Noise Contributions from Engine & Airframe[6]

[4] Boeker, Eric R., et al. (2008)
[5] Airports Commission (2014)
[6] Airbus (2003)

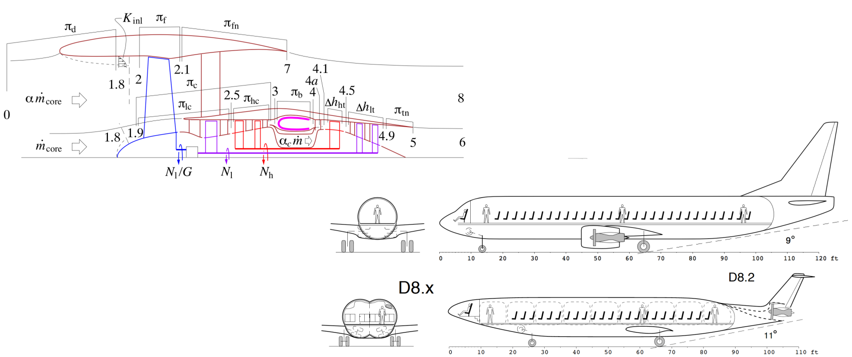
System Noise Analysis: Full Architecture



Aircraft Performance Representation: TASOPT vs. BADA 4

Custom Aircraft Design Tool

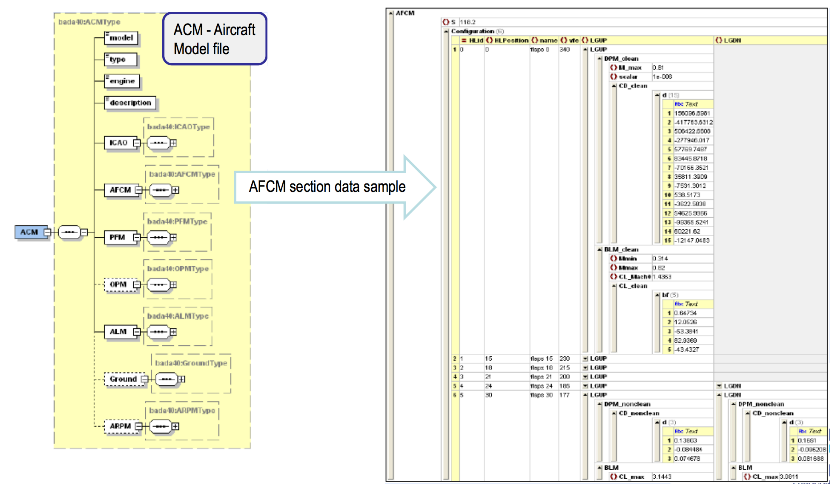
Transport Aircraft System OPTimization (TASOPT)[7,8]



- Written by Prof. Mark Drela (MIT)
- Physics-based aircraft sizing and optimization program
- Based on mission requirements, generates an optimal transport aircraft design, including:
  - Engine performance and geometry
  - Aircraft performance and geometry

Existing Aircraft Analysis Tool

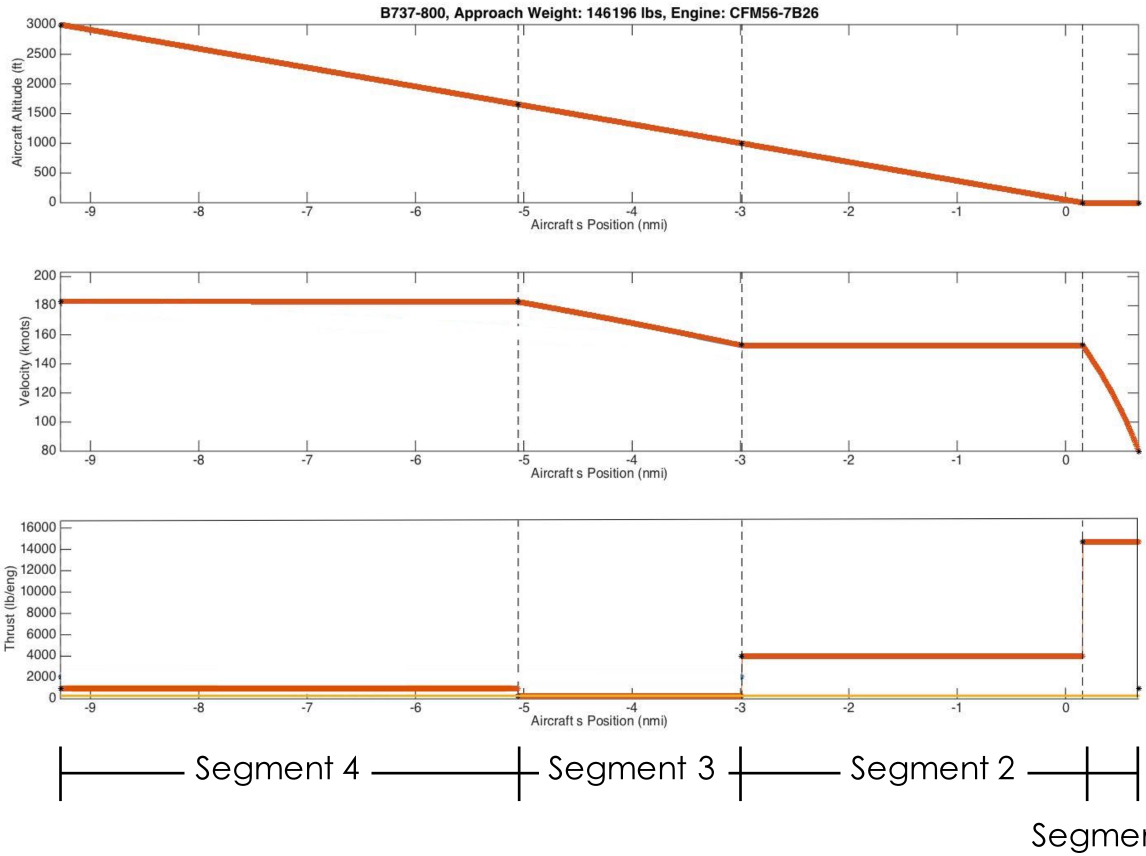
Base of Aircraft Data (BADA 4)[9]

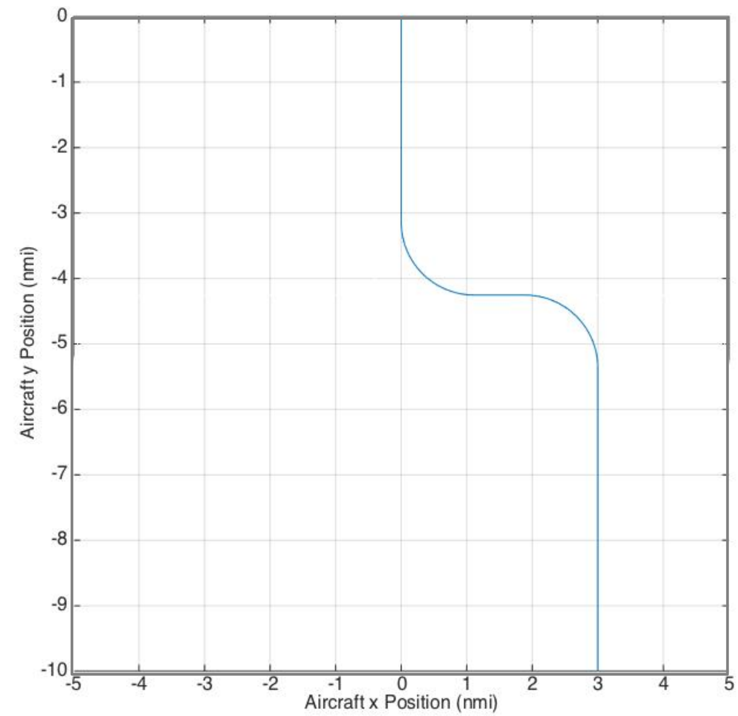


- Developed and maintained by EUROCONTROL
- Database of aircraft performance parameters obtained from aircraft manufacturers
- Provides:
  - Thrust values
  - Drag values for various configurations

[7] Drela, M. (2011)
[8] Drela, M. (2011)
[9] Eurocontrol (2015)

Approach Profile Generator





Example x, y Ground Track

- Generates position (altitude & distance along flight track), velocity, & thrust of an approach profile, including in flight & landing roll
  - Builds profile segment-by-segment, given specified requirements for each segment, starting from the runway touchdown point
  - Ground track is specified independently

Computation Methodology

- At each segment, variables are calculated using a force model & kinematics:

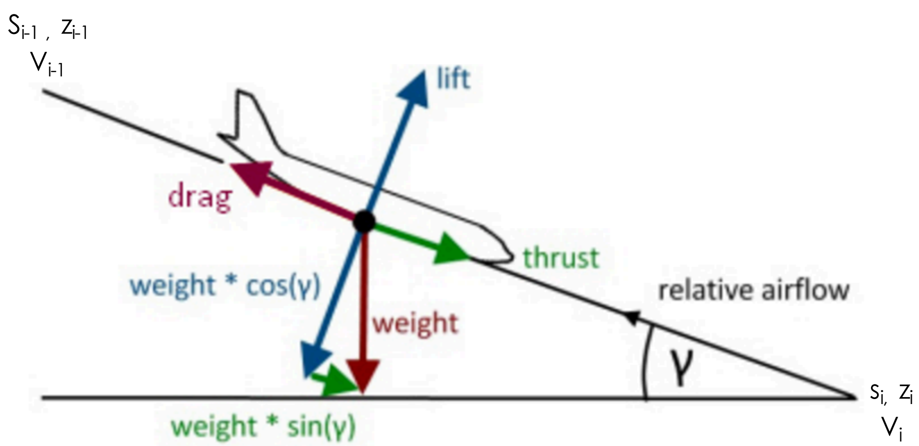
The user specifies:

$$\delta_{flap}, \delta_{gear}, \delta_{speedbrake}, V_i$$

two of: z_i, s_i, γ or T

The generator computes:

remaining two variables are calculated, using the equations below:



$$a = \frac{\sum F}{m} = \frac{T + W\sin(\gamma) - D}{W/g}$$

$$\frac{\Delta V^2}{2a} = \Delta s = \frac{\Delta z}{\sin(\gamma)}$$

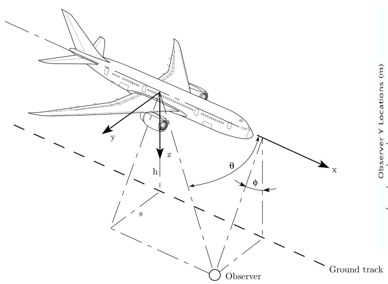
$$D = \frac{1}{2}\rho V^2 S C_D(\delta_{flap}, \delta_{gear}, C_L) \qquad C_L = \frac{W\cos(\gamma)}{\frac{1}{2}\rho V^2 S}$$

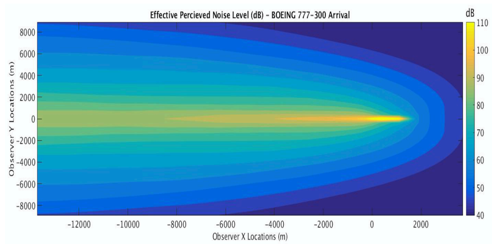
- s_i, z_i, V_i of one segment become $s_{i-1}, z_{i-1}, V_{i-1}$ of the next segment

Noise Model: ANOPP vs. AEDT

Custom Noise Analysis Tool

Aircraft NOise Prediction Program (ANOPP)[10]

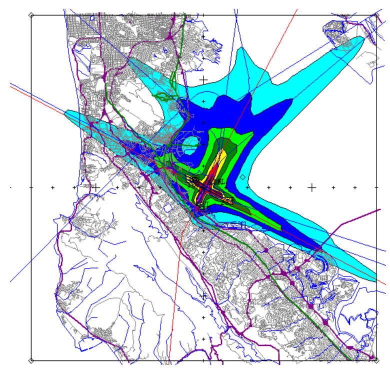


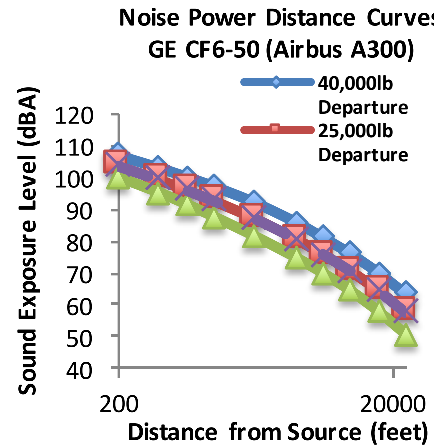


- NASA-developed program
- Computes far-field engine and airframe noise at an observer grid given various flight profile and configuration metrics
  - Semi-empirical calculations require detailed engine/aircraft performance inputs
    - e.g., Engine mass flow, areas, and temperatures, airframe geometry, etc.

Existing Aircraft Noise Analysis Tool

Aviation Environmental Design Tool (AEDT)[4]



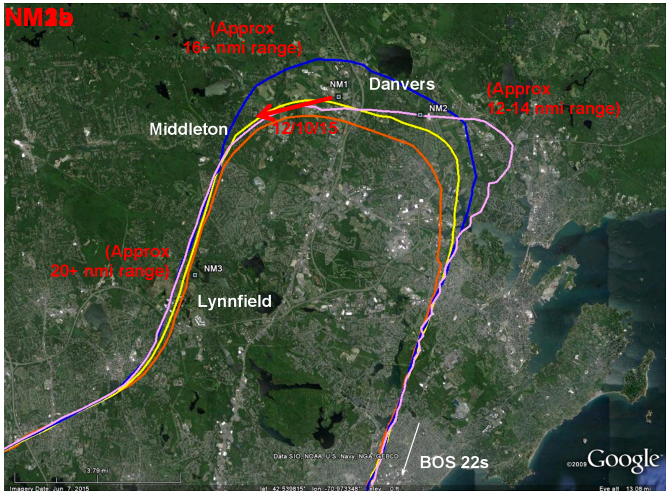


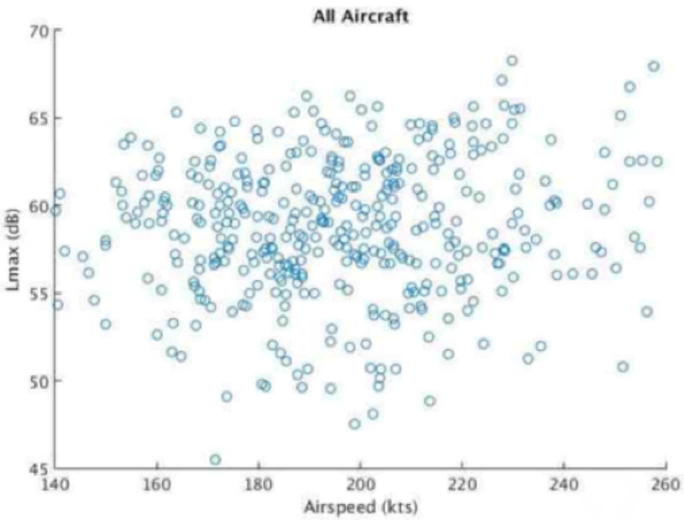
- Current industry standard model to evaluate aircraft noise impacts[8]
- Noise-Power-Distance (NPD) based computations
  - Interpolation from flight test data
- Assumes engine noise dominates aerodynamic noise

[12] Russel, J., Berton, J. (2012)

Validating Flight Profile & Noise Model with Boston Logan Airport Arrival Data

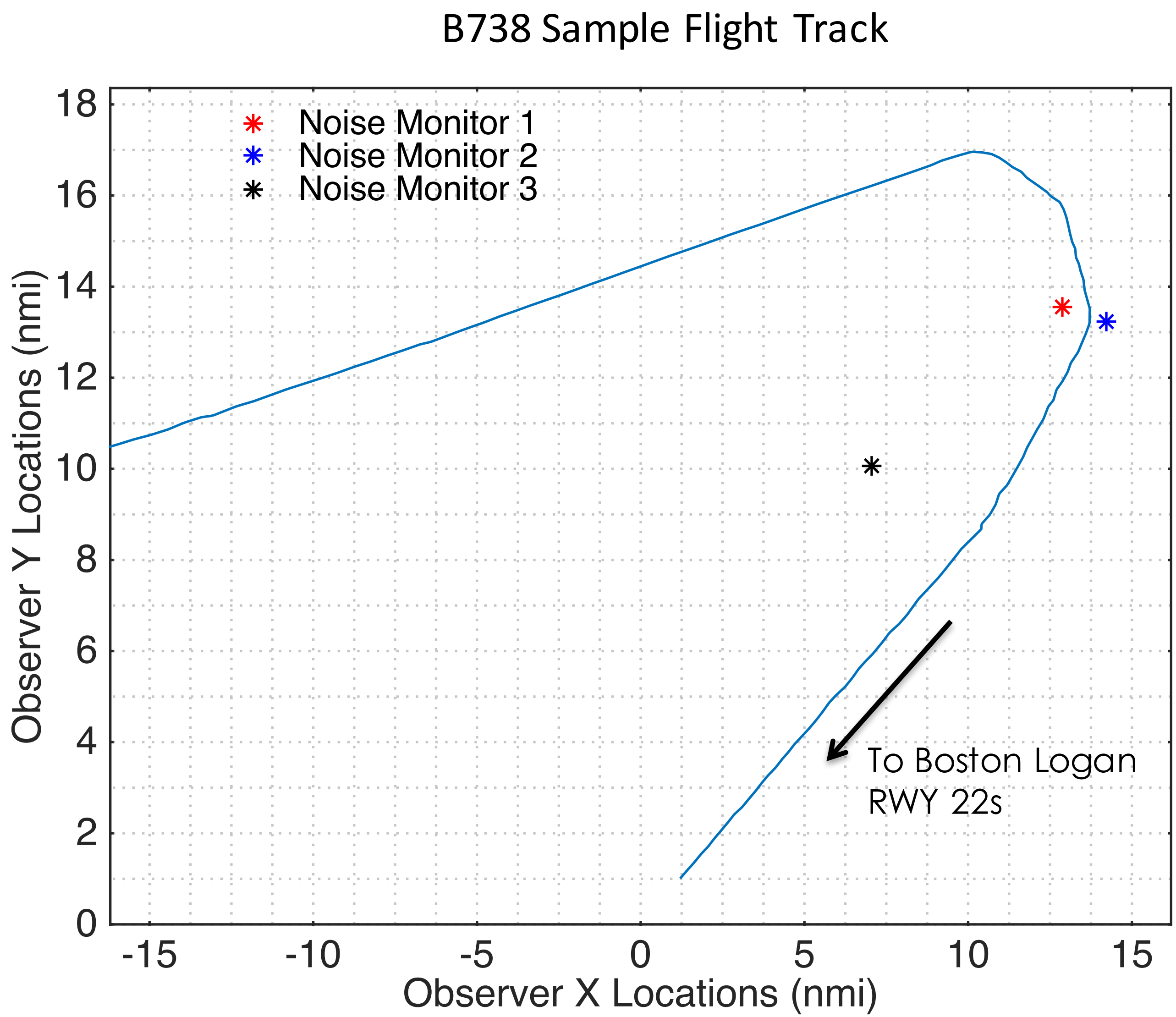
- Noise measurement campaign conducted from Nov. 2015 – Jan. 2016 in collaboration with MIT and Lincoln Laboratories
  - Noise measurements taken at 3 locations on approach to Boston Logan Runway 22s
  - Noise events correlated to specific flights
    - Flight tracks and speeds for each flight obtained from PDARS*
- Noise data can be used to check flight profile generator and noise model accuracy



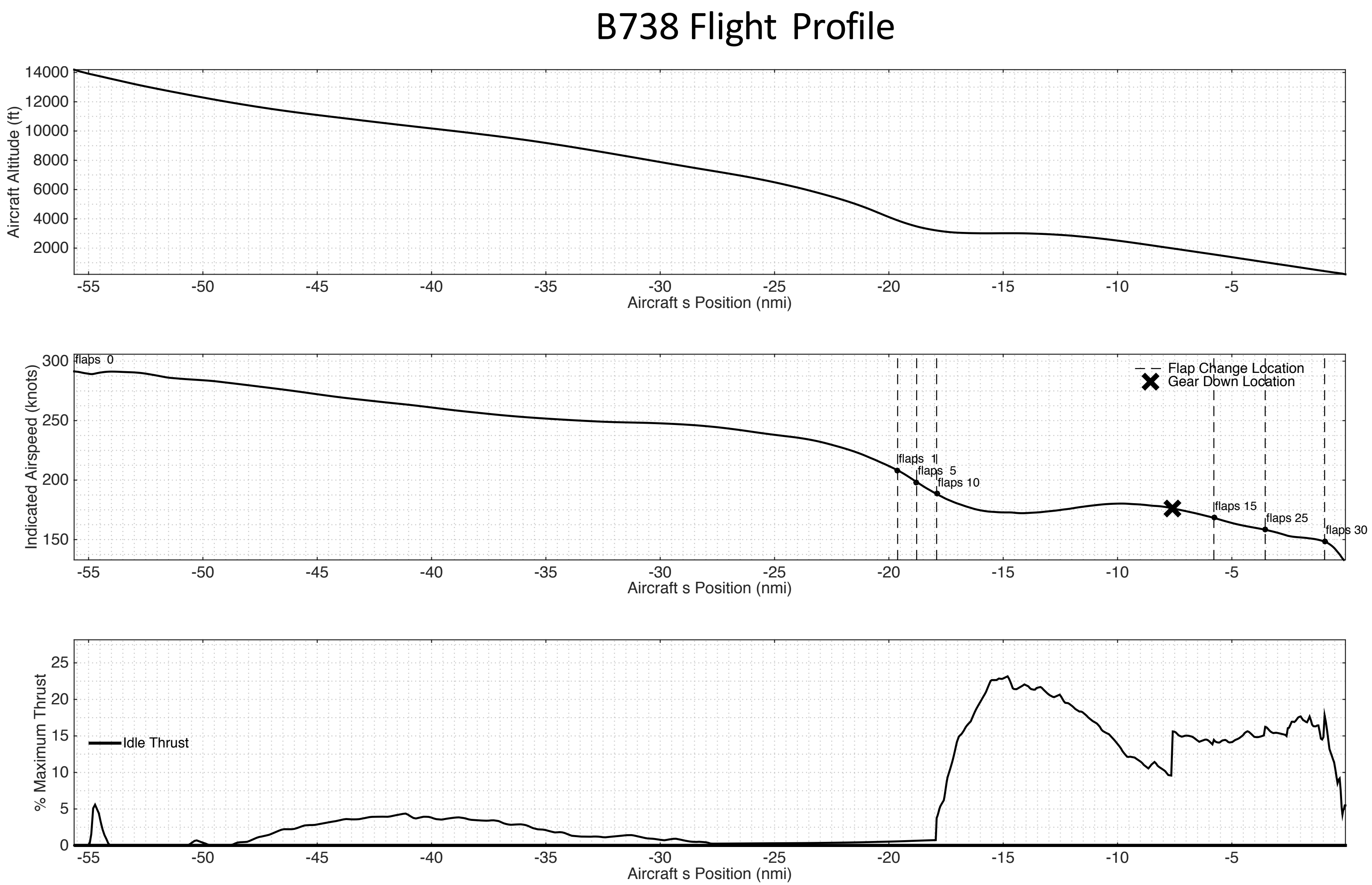


*Performance Data Analysis and Reporting System

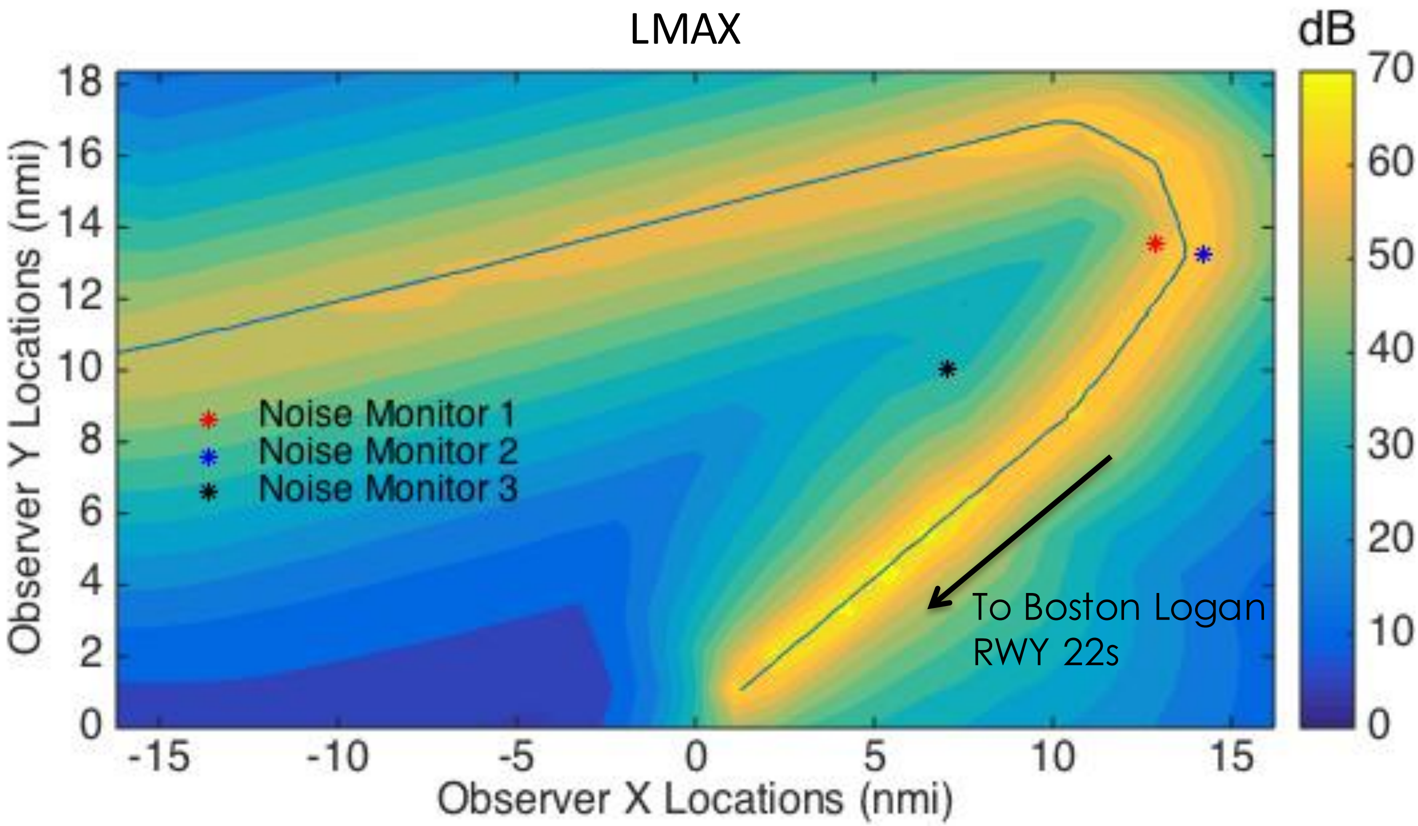
PDARS Data Sample Flight Track Data



BADA 4 Implementation: Computing Thrust from PDARS Data



Computing Noise from PDARS Data



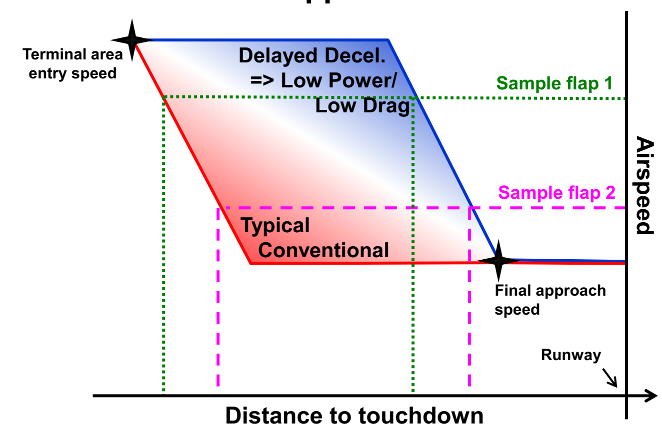
Preliminary

Noise Monitor	Lmax Measured (dB)	Lmax Computed (dB)
NM1	60.7	56.4
NM2	61.3	63.2
NM3	No Data Recorded	--

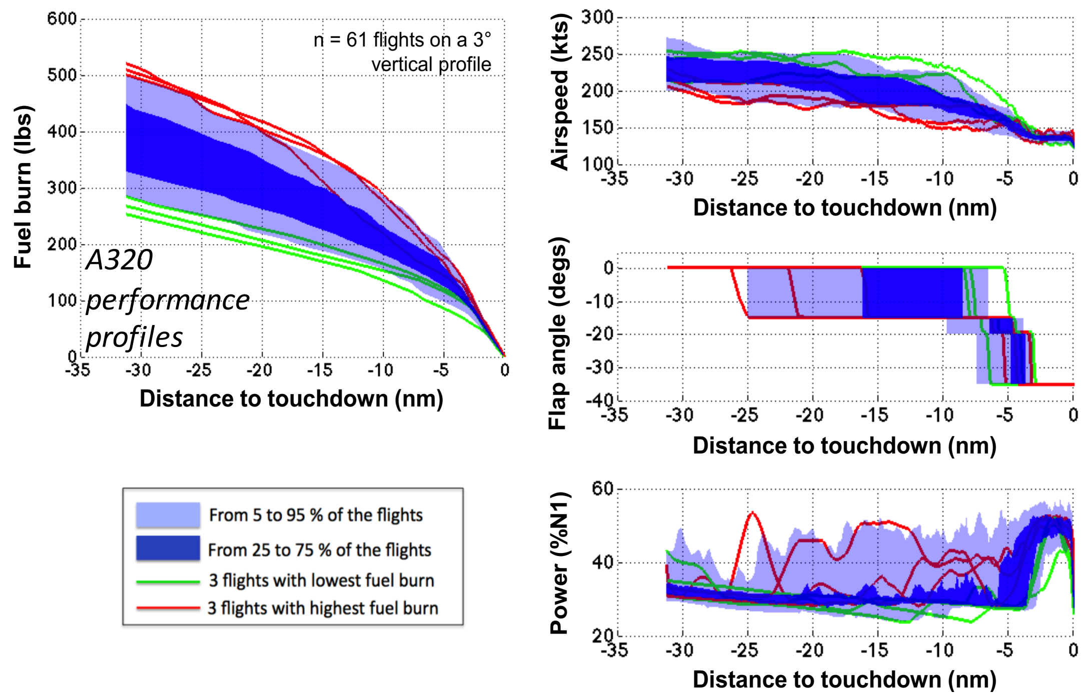
Example Application: Delayed Deceleration Approaches (DDAs)

- In conventional approaches, aircraft decelerate early in the approach
- DDAs provide potential for fuel burn and noise reduction[11]
- In DDAs, initial flap speed velocity held as long as possible during approach to lower drag and thrust requirements
  - Lower thrust levels reduce engine noise
  - Higher velocities increase airframe noise

Conventional Approach vs. DDA[11]

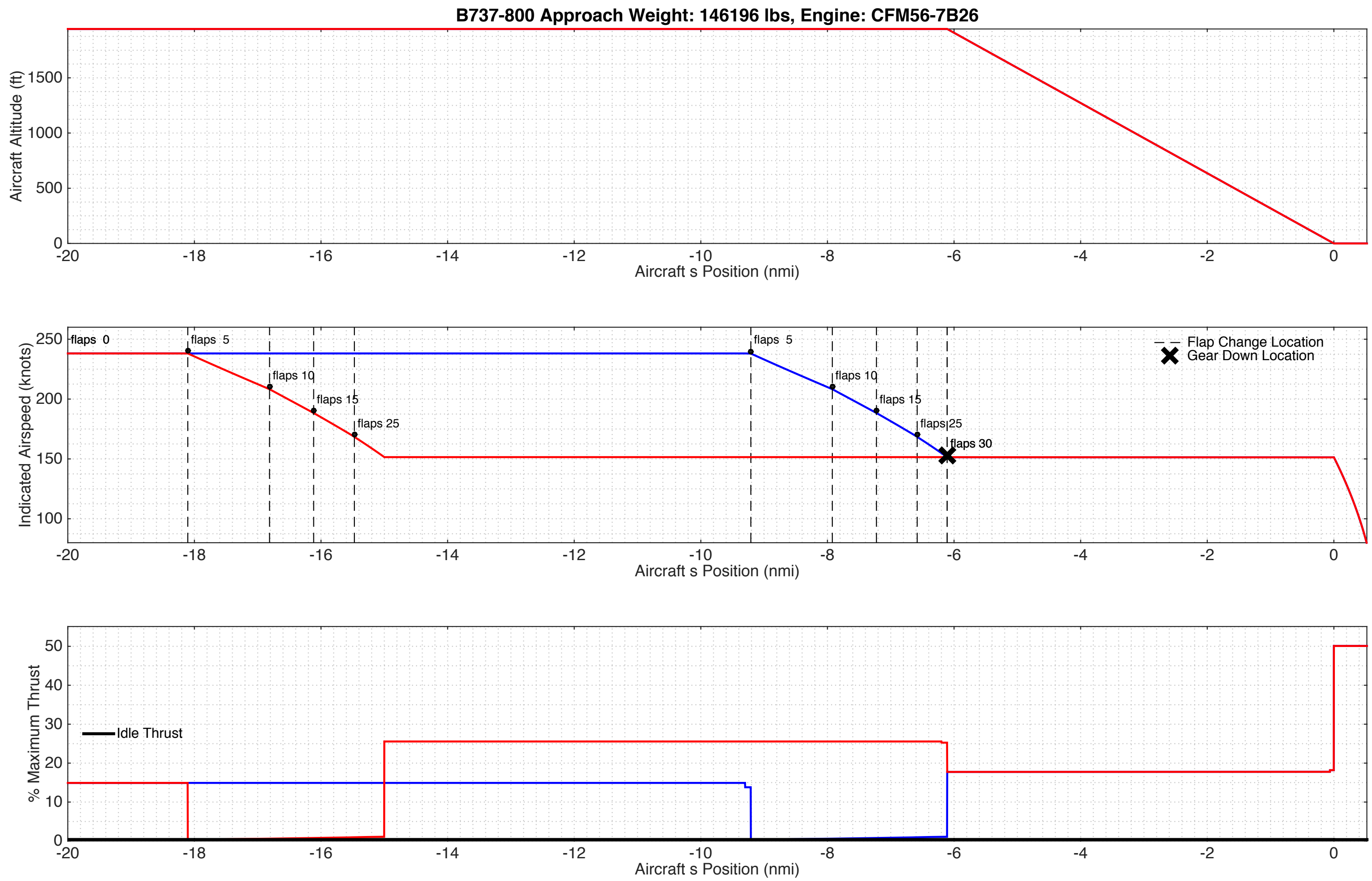


European A320 Flight Data Recorder Analysis (similar for B757 & B777)[12]



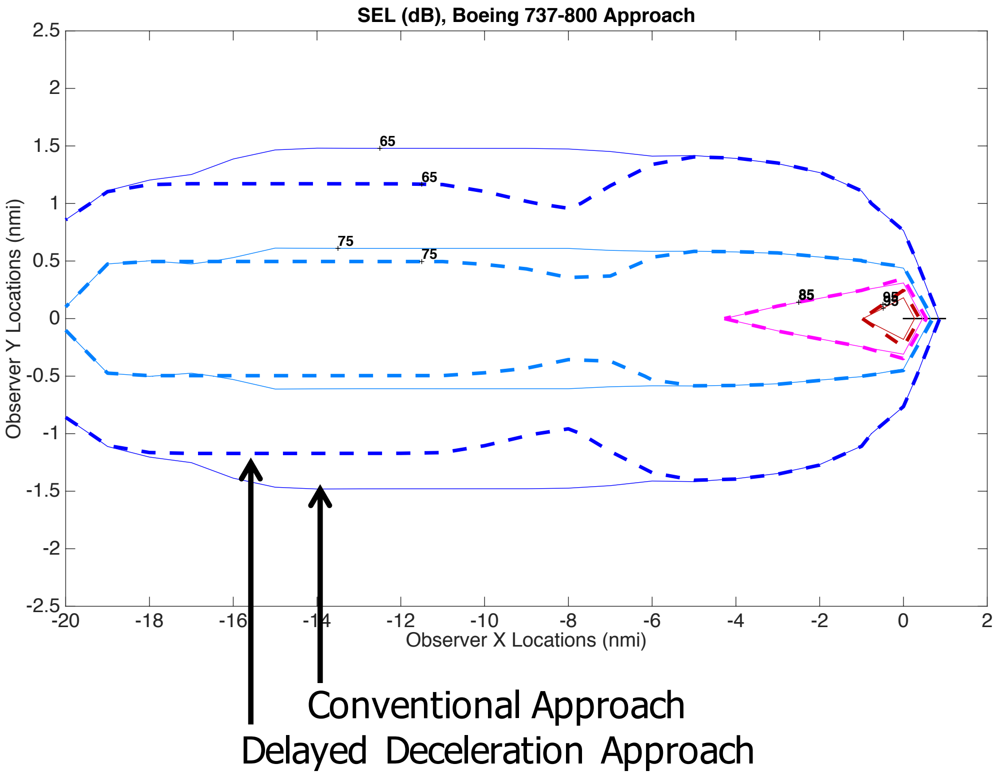
[11] Dumont, J., et al. (2012)
[12] Dumont, J., et al. (2011)

Conventional vs. Delayed Deceleration Approach Sample Flight Profile



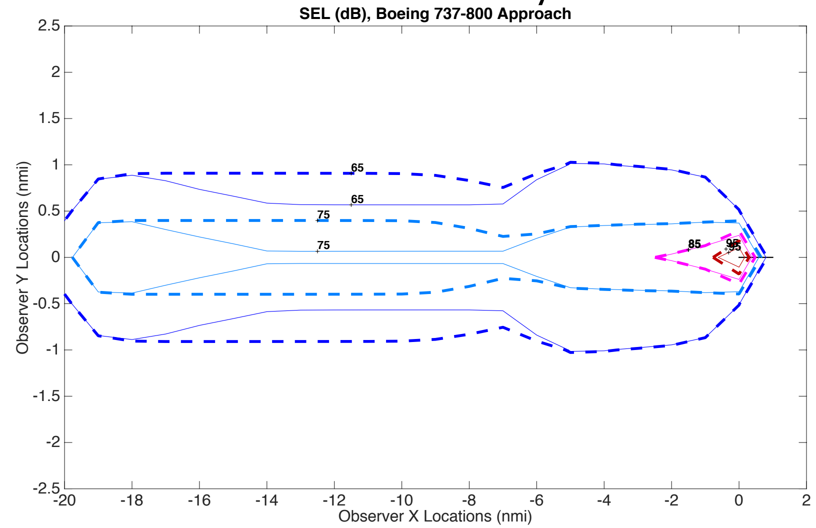
Conventional vs. Delayed Deceleration Approach Sample Flight Profile

Total Noise

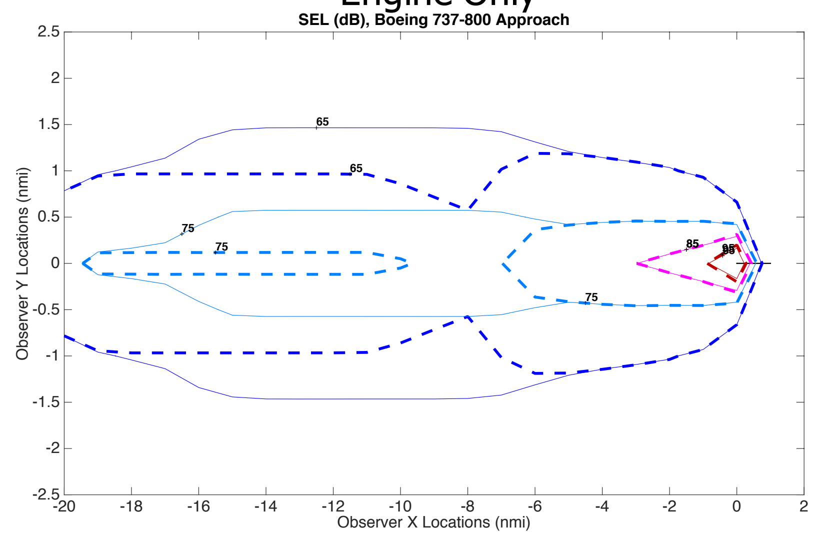


Preliminary

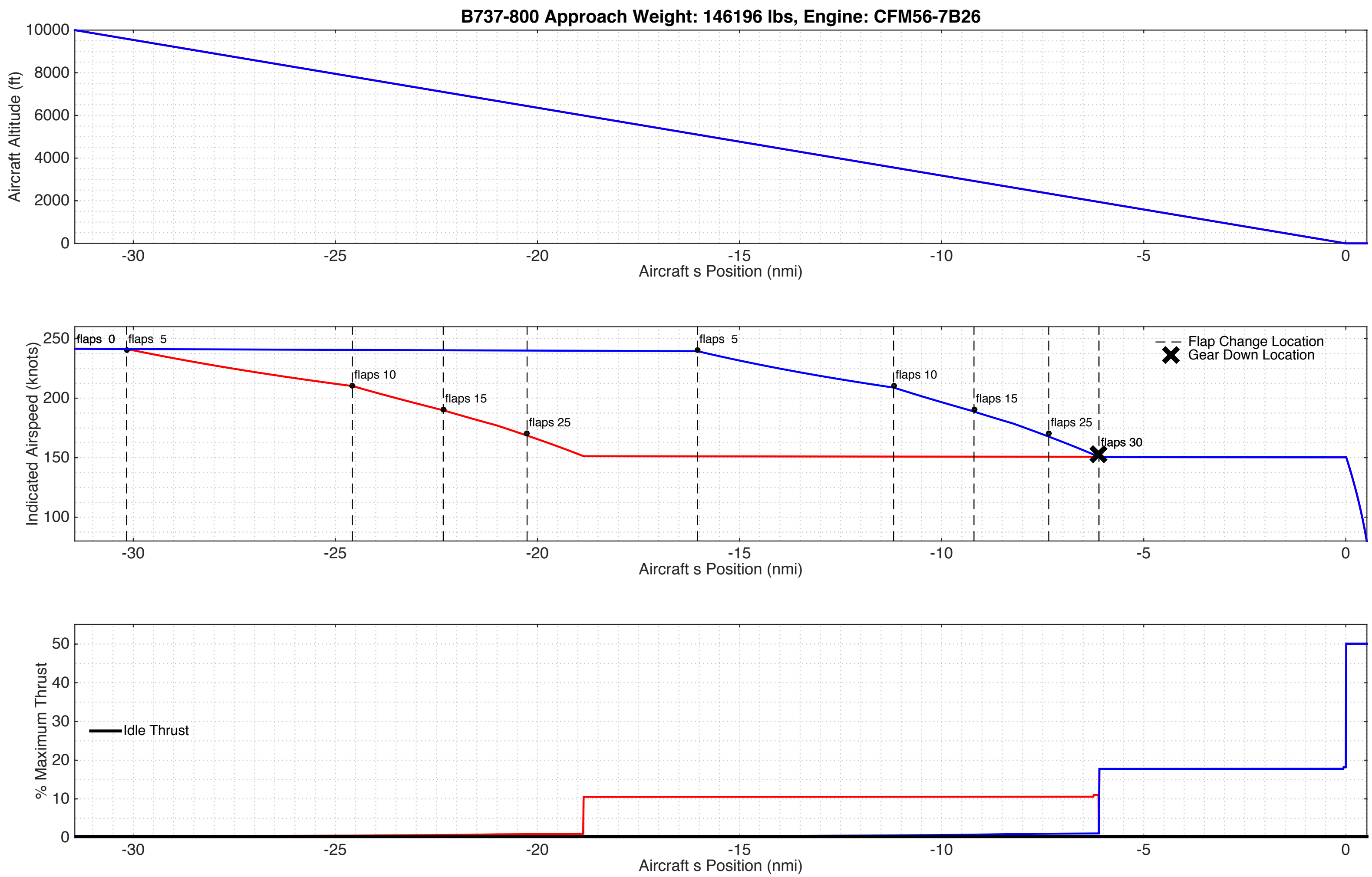
Airframe Only



Engine Only

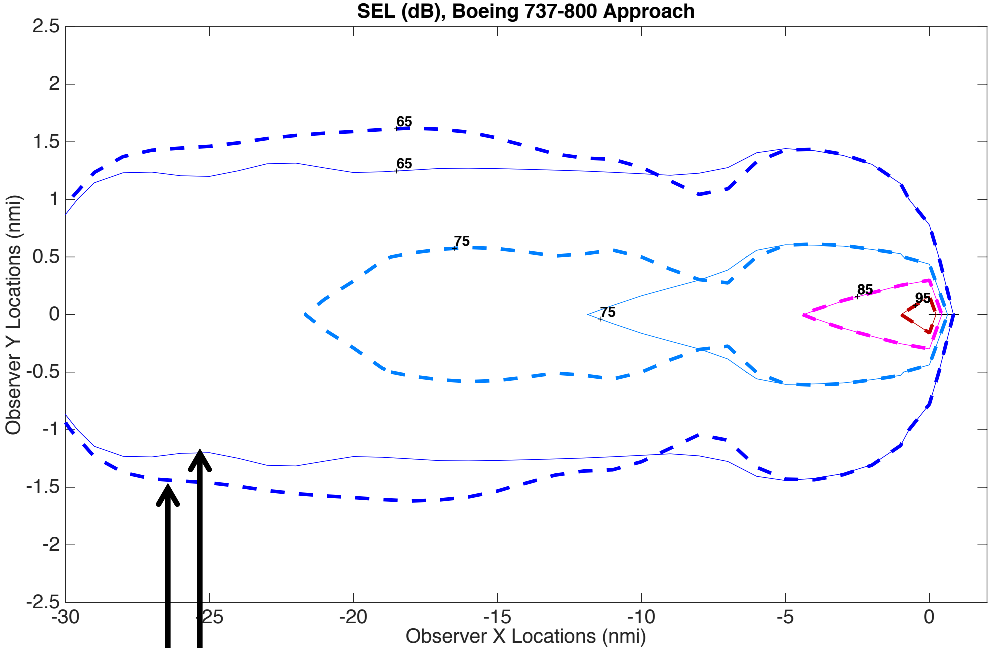


Continuous Descent vs. Delayed Deceleration Approach Sample Flight Profile



Continuous Descent vs. Delayed Deceleration Approach Sample Flight Profile

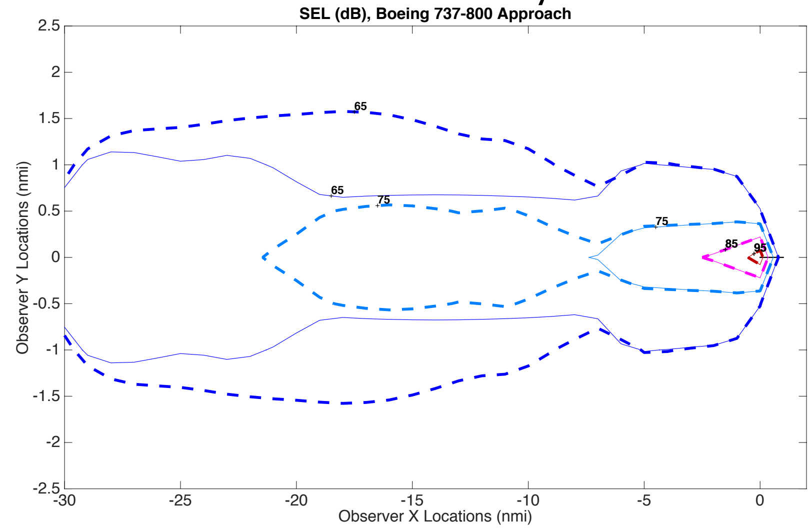
Total Noise



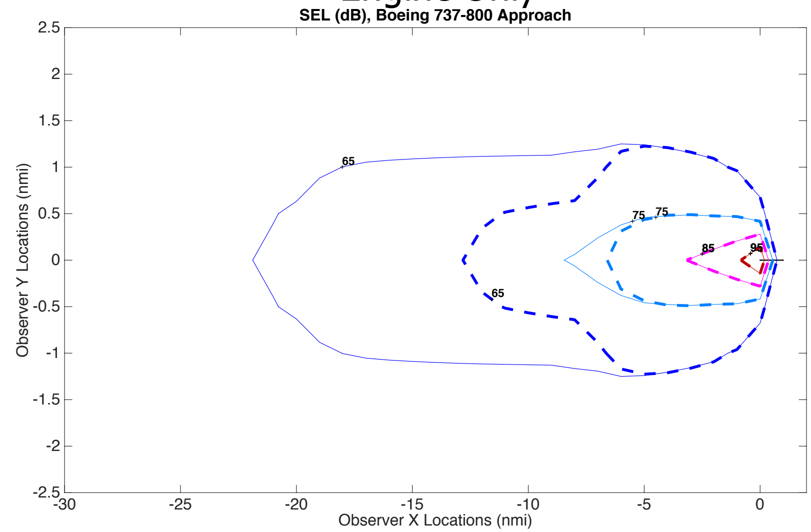
Continuous Descent Early Deceleration Approach
Continuous Descent Delayed Deceleration Approach

Preliminary

Airframe Only



Engine Only



Summary and Next Steps

- Summary:
  - Noise analysis framework has been developed to capture the noise impacts of advanced operational procedures performed by both current and future aircraft
  - This framework has demonstrated the capability of analyzing single-event user specified approach procedures
    - Currently being validated against BOS Noise Data
- Next Steps:
  - Generate thrust profiles for all flights in Boston Noise Measurement Campaign for evaluation in ANOPP and AEDT
    - Compare noise computations with measured data to improve modeling fidelity
  - Evaluate impact of various delayed deceleration approach procedures for various aircraft combinations on cumulative airport noise

Acknowledgements and References

- Acknowledgements:

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  - Tom Reynolds & Lanie Sandberg – MIT Lincoln Lab
  - Chris Dorbian & Joe DiPardo – FAA
  - Flavio Leo & Frank Iacovino - Massport

- References:

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  - [2] "Greener Skies over Seattle = Greener Skies Over the USA." Washington, DC, Federal Aviation Administration, NextGen (2012). https://www.faa.gov/nextgen/snapshots/stories/?slide=6
  - [3] "The Double Bubble D8 | NASA." National Aeronautics and Space Administration (2015). https://www.nasa.gov/content/the-double-bubble-d8-0
  - [4] Boeker, Eric R., et al. "Integrated noise model (INM) version 7.0 technical manual." Washington, DC, Federal Aviation Administration, Office of Environment and Energy (2008).
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  - [11] Dumont, J., Reynolds, T., Hansman, J., "Analyzing Opportunities and Barriers of Delayed Deceleration Approach Procedures to Reduce Fuel Burn." 12th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, Indianapolis, IN (2012) http://arc.aiaa.org/doi/abs/10.2514/6.2012-5591
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